DOCUMENT RESUME

ED 336 077 IR 015 089

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TITLE Effects of Control Mechanisms in Instructional Simulation.
PUB DATE 91
NOTE 31p.; Paper presented at the Annual Conference of the American Educational Research Association (Chicago, IL, April 3-7, 1991).
PUB TYPE Reports - Research/Technical (143) -- Speeches/Conference Papers (150)

EDRS PRICE MF01/PC02 Plus Postage.
DESCRIPTORS College Students; *Computer Assisted Instruction; *Computer Simulation; Higher Education; Intermode Differences; *Learner Controlled Instruction; *Man Machine Systems; Microcomputers; Multivariate Analysis; Prior Learning; Programed Instruction; *Skill Development; Student Attitudes

ABSTRACT

Instructional simulation is a type of computer assisted instruction that is effective for teaching dynamic skills. Control of instructional simulation may be fully automated (computer control), assigned to learners (learner controlled instruction), or control may be shared between computer and learner (learner control with advisement). The efficiency of these three mechanisms is examined for control of task difficulty, sequence of instructional activities, and pace (time on each activity). The efficiency of control mechanisms is partially determined by the characteristics of the criterion task and the learners' prior knowledge of the subject matter. An instructional simulation that teaches subjects to interpret an aviation display was developed to examine the effects of control mechanisms during the acquisition of a dynamic skill. Results of a pre-experiment and experiment 1 demonstrated that learners' strategies and time on task varied as a function of type of control over task difficulty, and that learners may not be able to effectively control sequence and pace when the subject matter is unfamiliar. Experiment 2 will investigate control of sequence and pace. (16 references) (Author/DB)

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EFFECTS OF CONTROL MECHANISMS IN INSTRUCTIONAL SIMULATION

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Abstract

Instructional simulation is a type of computer-based training that is effective for teaching dynamic skills. Control of instructional simulation may be fully automated (computer control), assigned to learners (learner control), or control may be shared between computer and learner (learner control with advisement). The efficiency of these three mechanisms is examined for control of task difficulty, sequence of instructional activities, and pace (time on each activity). The efficiency of control mechanisms is partially determined by the characteristics of the criterion task and learners' prior knowledge of the subject matter. An instructional simulation that teaches subjects to interpret an aviation display was developed to conduct the experiments. Experiment 1 demonstrated that learners' strategies and time on the criterion task varied as a function of type of control over task difficulty. Results of a pre-experiment indicate that learners may not be able to effectively control sequence and pace when the subject matter is unfamiliar. Experiment 2 is currently being designed to investigate control of these variables. Implications for designing control mechanisms are discussed.

EFFECTS OF CONTROL MECHANISMS IN INSTRUCTIONAL SIMULATION

State-of-the-art microcomputer systems are capable of providing a wide variety of control mechanisms for instruction. In some contexts the extent of learners' control over the instruction can effect the time they spend on a lesson (Ross & Rakow, 1981), their performance on certain tasks (Avner, Moore, & Smith, 1980), and their continuing motivation to complete a lesson (Kinzie & Sullivan, 1989). However, prescriptions have not yet been developed that specify the type of control mechanisms that are most appropriate for different instructional contexts (Goetzfried & Hannafin, 1985; Klein, 1988). This paper discusses the effects of different methods for controlling task difficulty, sequence, and pace during the acquisition of a dynamic skill.

Instructional simulations have proven to be effective for training dynamic skills (Reigeluth and Schwartz, 1989). Instructional simulations are designed to teach learning outcomes that are quite different from written instruction or conventional computer-assisted instruction (CAI). Ruben and Lederman (1982) list five components of simulation and games that are also found in instructional simulations:

"(1) participants cast in roles; (2) interactions between those roles; (3) rules governing those interactions; (4) goals with respect to which interactions occur; and (5) criteria for determining the attainment of the goals and the termination of the activity" (p. 235). The emphasis is on interactivity which usually takes the form of learners' decisions and actions during practice of a complex task. In contrast, most written instruction and CAI involve the acquisition of "knowledge structures." Munro, Fehling, and Towne (1985) contrast knowledge structures, "coherent bodies of essentially propositional information," with dynamic skills, "a complex of perceptual, motor, and decision-making skills such as are called for in many real world tasks" (p. 50). Mastery of knowledge structures is usually accomplished by reading, encoding, and retaining verbal information and is demonstrated by providing verbal responses to questions. However, dynamic skill is measured as a function of a learners speed and accuracy for performing a task that requires simultaneous motor and cognitive processes.

Many computer games involve simulations that have varying levels of difficulty. When controlled by the computer, difficulty is usually adjusted based on the

learner's current ability to perform the task(s). This keeps the activity exciting and challenging. Malone (1981) has indicated that variable task difficulty is one of the most motivating components of computer games. However, Klein (1988) states that "...learners may not be the best judges when given control over item difficulty [during the course of instruction]" (p. 25). It is still unclear whether control over task difficulty should be controlled by learners or varied automatically by the computer (Mattoon, Klein, & Thurman, 1991).

Johansen and Tennyson (1983) recommend that learner control features of CAI be combined with advice to learners to help guide their control decisions. Tennyson (1980) administered three forms of instructional control via CAI that taught physics concepts: (1) learner control with advisement (LCA) that provided learners with control over sequence and amount of instruction and gave diagnostic and prescriptive advice on control decisions; (2) the same learner control (LC) but without advice; and (3) computer control (CC) which automatically varied sequence and amount of instruction. The CC and LCA treatments produced the best performance on a criterion test. Subjects in the LC treatment spent less time on

the lesson and apparently quit the lesson too early to master the material.

Research on control of sequence has been shown to change as a function of the type of subject matter. Sasscer and Moore (1984) provided LC options for sequence in a CAI program that taught English and math skills to undergraduates. Learners chose different strategies for attaining lesson objectives. For example, one strategy was to study a rule, then an example, and then a practice activity, while another was to study a rule and go directly to practice. They found that certain strategies appeared to produce the best learning but differed for English and math instruction.

Schloss, Wisniewski, & Cartwright (1988) found that effects of control over remediation varied for different type of verbal skills. Undergraduates responded to two different types of questions after completing a CAI lesson on special education: (1) "untrained items" were questions based on but not contained in the content material and (2) "trained items" were taken directly from the content. Subjects who were forced to review content after a wrong answer on a practice exercise performed better on the untrained test items than subjects who were allowed to

bypass review. However, this effect was reversed for the trained items. In a similar experiment Avner, Moore, & Smith (1980) hypothesized that advancing learners to new material in a lesson as soon as mastery is demonstrated increased instructional efficiency. They examined the performance of undergraduates on a chemistry experiment after completing a CAI lesson on lab procedures. Subjects who were advanced based on mastery performed better on the task but spent more time on the lesson than subjects who controlled their own advancement.

The experiments described below were designed to examine the effects of control mechanisms in an instructional simulation during the acquisition of a dynamic skill.

Experiment 1

The effects of three types of mechanisms that controlled task difficulty during practice were examined: learner control with advisement (LCA), learner control without advisement (LC), and computer control (CC). Observations were made on learners' use of control options and their effects on performance and retention of skill for interpreting a complex visual display. Subjects' speed and accuracy is recorded during both practice and assessment activities.

Performance was examined on an immediate test and a test administered one week after the lesson.

Method

Participants

Subjects were 78 undergraduates enrolled in the same course in the College of Education at a large public university in the Southwestern United States. They participated in the experiment for partial course credit and had no prior knowledge of the subject matter.

Materials

The instructional simulation taught subjects how to interpret the digital and symbolic information of a simulated cockpit display called the Head-Up Display (HUD). The criterion task was to use the information to "locate target aircraft" on a two dimensional plane called the "Overhead." The LC and LCA versions of the program provided learner control over the criterion for earning performance points during practice. The CC version controlled point criterion as a function of the subject's current level of performance. The HUD and the Overhead are shown in Figure 1.

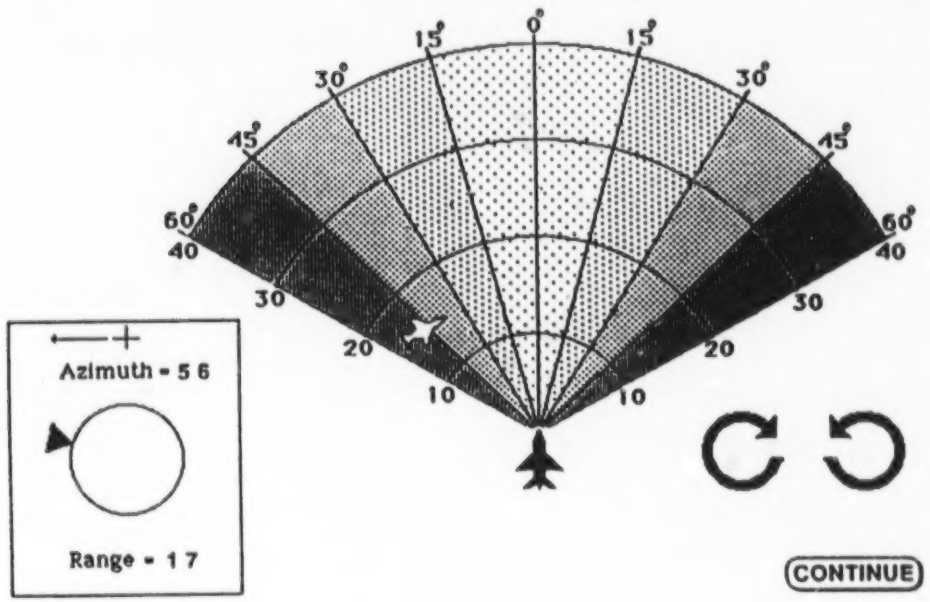

Figure 1

All three versions of the program contained an instructional sequence that presented information and exercises on: (1) estimating target range, a linear distance of three to eight centimeters from the target coordinates to the bottom center of the Overhead; (2) estimating target azimuth, an angle of 30 to 120 degrees created by the target's position relative to the vertical dividing line passing through the center of the Overhead; and (3) estimating target heading, the direction of the targets flight from zero to 360 degrees. The program recorded time on task and degree of accuracy for moving an icon called the "Locator" to

a position that described the range, azimuth, and heading of the target. Accuracy was computed as the degree of error in these three measures. Activating the "Continue" button displayed the target at its correct range, azimuth, and heading, points earned or lost for speed and accuracy, and two linear scales indicating the current level of difficulty. Cumulative feedback for speed and accuracy and the subject's total score was displayed every five trials. Two 25-target sequences served as immediate and delayed tests. Values for range, azimuth, and heading were randomly generated for practice and each test. The target, points, and scales are shown in Figure 2.

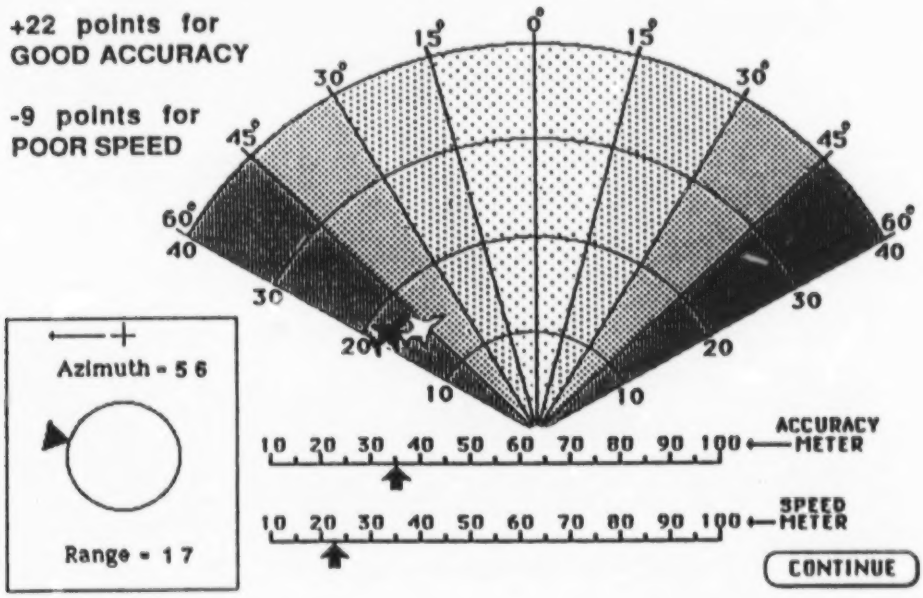

Figure 2

Increasing the level of difficulty for speed or accuracy resulted in two changes in the criterion for earning points: (1) a larger number of points could be earned or lost and (2) responses had to be faster (speed difficulty) and executed with less error (accuracy difficulty) to earn points. The position of the pointer on each scale indicated the current level of difficulty. Speed and accuracy were equivalent in point value, and their level of difficulty was adjusted independently. However, subjects were prevented from earning speed points when their error in range, azimuth, or heading exceeded the limits of the current level of difficulty.

The LC treatment enabled subjects to adjust level of difficulty by moving the pointers up or down the speed and accuracy scales. The LCA treatment gave subjects the same control but also displayed specific advice (e. g., "set the speed challenge to 35") based on their cumulative performance over the most recent five trials. If a subject had succeeded in earning points for speed in the last five trials, the program would advise a proportional increase in speed difficulty. If points were lost for speed, a decrease was recommended. Advice for level of difficulty of accuracy was administered the same way. In the CC

treatment, difficulty level was automatically set using the same algorithm that generated advice in the LCA treatment.

Procedures

The experiment was a two variable mixed design with repeated measures on test occasion (immediate and 7-day delayed). An equal number of subjects were assigned to treatments based on the order they arrived at the computer laboratory. Subjects completed a lesson and skill test for using the mouse, read descriptive information on the HUD, completed a practice activity and a test, and returned a week later to complete the delayed test.

Subjects' response speed was recorded as the time interval from the onset of the information displayed in the HUD to the time the subject clicked on the Continue button. Accuracy was computed as the degree of error in estimate for range, azimuth, and heading. Two scores were computed for each test by averaging speed and accuracy across the 25 trials.

Multivariate analyses of variance (MANOVA) were conducted to analyze subjects' practice and test performance and adjustments in task difficulty. Subjects' initial skill for using a mouse served as a covariate to isolate the criterion skill. The

significance level was set at $p<.05$ for all multivariate and univariate tests.

Results

Performance on Immediate and Delayed Tests

Table 1 displays means for task time on the mouse skill test, criterion task time, and accuracy for practice, immediate test, and delayed test. Means for range, azimuth, and heading error were transformed to standard scores and combined into one measure of accuracy. The sign for accuracy scores was reversed so that positive scores indicate superior performance. All means are adjusted for the covariate.

Table 1

Means: Covariate, Task Time, and Accuracy.

Group		Practice		Test 1		Test 2	
	Covariate	Tm	Ac	Tm	Ac	Tm	Ac
LCA	11.7	16.0	-0.17	14.1	0.29	15.8	-0.40
CC	11.9	15.3	0.13	14.4	-0.14	14.4	0.09
LC	12.6	15.3	0.04	13.0	-0.15	14.6	0.31

LCA = learner control with advisement

CC = computer control

LC = learner control without advisement

The MANOVA did not reveal a significant main effect for learner control treatments ($F(8,108)=0.62$, $p>.05$), but a main effect did occur for test occasion ($F(4,57)=6.02$, $p<.001$). Univariate analyses revealed an interaction for treatment by test occasion for task time ($F(2,57)=4.41$, $p<.05$). LC subjects performed the task more quickly on the immediate test than the CC or LCA subjects ($M=13.0$ vs. $M=14.4$ and $M=14.1$ seconds) but performed at about the same rate on the delayed test ($M=14.6$ vs. $M=14.4$ and $M=15.8$).

Control Decisions

A second MANOVA was conducted on points and levels of difficulty. It revealed a significant main effect for treatment ($F(2,38)=4.48$, $p<.05$). Univariate tests indicated that LCA subjects set higher levels of difficulty for accuracy than LC subjects ($M=60.2$ vs. $M=41.3$, $F(1,39)=8.91$, $p<.01$) but gained less accuracy points ($M=38.5$ vs. $M=56.7$, $F(1,39)=4.92$, $p<.05$) per target. Also, LCA subjects adjusted difficulty level more frequently for speed and accuracy than LC subjects ($F(4,36)=5.61$, $p<.01$). Differences in frequency of adjustments for accuracy and speed were $M=14.1$ vs. $M=6.4$, $F(1,39)=23.4$, $p<.001$ and $M=10.0$ vs. $M=5.3$, $F(1,39)=10.71$, $p<.01$ for respectively.

Performance on Practice Trials

To develop control mechanisms for Experiment 2, performance across practice trials was analyzed. Subjects did not appear to improve on speed or accuracy after about 35 trials. This seemed to agree with subjects' estimates of the number of targets located before "loosing interest" ($\underline{M}$=32) and becoming "physically tired of the task" ($\underline{M}$=34).

Discussion

The lower difficulty levels chosen by LC subjects may have altered their perception of their performance. By following advice or being advanced to higher levels of difficulty, LCA and CC subjects had to respond with greater accuracy to earn points. This probably compelled them to take more time adjusting the Locator during the immediate test, even though taking more time did not result in significantly greater accuracy.

Subjects apparently concentrated on what they perceived to be the most important aspects of the performance. LCA subjects were advised to increase levels of difficulty for accuracy and lost accuracy points more often than LC subjects, so they spent more time on the task in the attempt to produce more accurate responses. LC subjects kept the level of difficulty low. Although they did not accumulate any more points than LCA or CC subjects, they did reduce

the risk of receiving negative feedback (loss of points). This strategy probably increased their confidence and enabled them to strive for greater speed.

Experiment 2 (in progress)

The instructional simulation used in Experiment 1 is being modified to examine control over sequence and pace using LC, LCA, and CC control mechanisms. LC enables subjects to move about freely among different instructional activities. LCA provides the same control as LC but delivers advice on advancing to different instructional activities. CC operates the same way as the LCA treatment except subjects are automatically advanced to each activity. Content material and criterion tests are the same as in Experiment 1.

Materials

The instruction for Experiment 2 is divided into three instructional sequences, a practice activity, and a test. Each of the sequences contains five to 16 "pages" of text and illustrations describing one of the subtasks (e. g., estimating range) for locating targets. The subject is able to move forward or back through the pages of each sequence. Additionally, each sequence contains exercises that provide feedback on

speed and accuracy. Subjects receive the same type of performance feedback during practice as in Experiment 1, but the difficulty level is held constant.

LC subjects control advancement through the instructional activities and begin the test when they feel they are ready. Both LC and LCA versions of the program provide subjects with "buttons" that allow them to move freely among instructional sequences, exercises, and practice and to advance to the test. LCA subjects receive advice on control decisions based on their performance on the exercises and practice. For example, subjects are advised to move on to the next instructional sequence, practice, or the test when response speed and accuracy reach the mastery level assigned to the activity. Mastery is based on results of Experiment 1 and the pre-experiment. The CC version of the program makes control decisions the same way as the LCA version, but automatically advances subjects through the lesson.

Procedures for Pre-Experiment and Experiment 2

Subjects were recruited for the pre-experiment from the same population as Experiment 1. Ten subjects, five males and five females, completed the LC version of the program. Each subject could earn up to $15 for each test. A proportion of this sum was earned

based on the total speed and accuracy points.

An additional reward condition is planned for Experiment 2. Each subject will earn up to $5 per test as a function of "learning speed" (time spent on instructional sequences and practice prior to the immediate test). For example, subjects who begin the test in less than 20 minutes will receive $5 in addition to the amount they earn for performance points. Subjects who spend from 20 to 60 minutes will receive a proportion of this amount. This represents a range approximately one standard deviation above and below the mean time pre-experimental subjects spent in the lesson.

Results from Pre-experiment and Discussion

Performance

Means for speed and accuracy points and monetary rewards are presented in Table 2. Table 3 displays means for task time and accuracy. Prior to converting accuracy measures to standard scores, error in estimations of range, azimuth, and heading were compared to results of Experimental 1. Test performance was similar, but pre-experimental subjects appeared to perform with less accuracy and speed during practice than subjects in Experiment 1. This is probably because Experiment 1 required completion of

instruction prior to practice. Seven of the 10 pre-experimental subjects chose to go to the practice activity after examining only a short overview of the criterion task.

Table 2

Means: Performance Points and Monetary Rewards.

Gender	Test 1		Test 2	
	Points	Reward	Points	Reward
Male	1523	$9.14	1477	$8.86
Female	1214	$7.28	1196	$7.18

Table 3

Means: Covariate, Task Time, and Accuracy.

Gender		Practice		Test 1		Test 2	
	Covariate	Tm	Ac	Tm	Ac	Tm	Ac
Male	8.1	16.3	0.39	12.9	0.06	12.3	-0.12
Female	11.3	20.4	-0.39	14.5	-0.06	14.0	0.12

Although 10 subjects are too few to make reliable predictions, the means seem to indicate that males

performed at greater speed. Also, the mean number of practice trials was 63 for males and 32 for females. Males appeared to spend less time on each practice target (M=28 s) than females (M=44 s). Experiment 2 will examine effects for gender.

Control Decisions

Subjects appeared to choose different strategies for learning the criterion task. Although, the program begin with a concise overview for estimating range, azimuth, and heading, performance data and observations made by the experimenter indicate that subjects advanced to the practice activity before they fully understood how to estimate heading.

Subjects spent an average of two, four, and 10 minutes covering instruction on range, azimuth, and heading respectively. Half the subjects skipped all the exercises in the instructional sequences. Those who completed exercises on the subtasks spent an average of only six, nine, and 23 seconds estimating range, azimuth, and heading respectively. This was probably not enough time to prepare for practicing the "whole" task. Apparently subjects did not understand the value of learning each aspect of the task before attempting the whole task of locating targets. This seems the most likely cause of poor performance during

practice.

Task analysis and data from Experiment 1 have indicated that the most complex and difficult aspect of the target-location task is estimating heading. However, only four subjects chose to go back to the heading instruction when they realized (by examining feedback) their estimates were not accurate. Four subjects reported that they "knew they were missing something" or "could not understand" how to estimate heading. They were encouraged to continue and told "the information they needed was available in the program." The experimenter observed that these subjects required 15 to 30 additional minutes of lesson time to determine how to properly estimate heading.

Attitude

Subjects responses to bipolar attitude statements about their learning experience were examined. The measures ranged from -1.0 (strongly disagree) to 1.0 strongly agree. Subjects tended to be positively inclined toward controlling sequence (M=0.72) and pace (M=0.95). Although practice data and observations of the experimenter indicated that subjects experienced difficulty locating essential information in the instruction, they also expressed confidence in their control decisions. The means for the statements, "I

was able to determine when it was best for me to begin the test..." and "I was able to determine what type of feedback I needed..." were 0.65 and 0.70 respectively.

General Discussion

Overall, the results of Experiment 1 and the pre-experiment indicate that the efficiency of instructional simulation may be improved by advisement and computer control mechanisms. Steinberg (1989) emphasizes that the less learners know about the subject matter, the less successful they will be in making control decisions. This is because they lack the "ability to discriminate between critical and tangential information" (p. 120). The subject matter in Experiment 1 and 2 is not only unfamiliar but is but is quite different than academic skills common to undergraduate study.

In Experiment 2, it is expected that LCA and CC mechanisms will identify specific deficits in performance and guide subjects to appropriate instructional activities. This should enable LCA and CC subjects to acquire subskills more quickly than LC subjects. Finally, contrary to learners' preference for control, Experiment 2 should demonstrate that learners are not able to make effective control decisions during the acquisition of an unfamiliar skill

without advisement.

Schloss, Wisniewski, and Cartwright (1988) state that "research to date has, in general, demonstrated that program [computer] control is more effective than learner control in aiding student learning" (p. 142). Different control mechanisms seem to vary along a "control continuum" ranging from total learner to total computer control. Johansen & Tennyson (1983) and Tennyson (1980) devised a mechanism that analyzed pretest and on-task performance during instruction and advised learners on control decisions. This type of mechanism is probably located near the middle of the control continuum because computer and learner share control of the instruction. Learners are given the final choice of control actions, but the computer directly influences their perception of their need, and this influences their control decisions. Shared control has shown advantages over mechanisms controlled solely by computer or learner. Shared control would seem to be most effective in situations where the criterion task is very complex, and predictions based on performance analyses may not always be accurate. This type of control mechanism lets learners "fine tune" control decisions that are based on probability and may not always be correct. When advice appears to

be inaccurate, a learner can reject it based on a personal, and perhaps better, understanding of current needs.

Munro, Fehling, and Towne (1985) showed that learner control of feedback in an instructional simulation had advantages over computer control during practice of an ongoing dynamic task. They conclude that feedback can interfere with perceptual and cognitive processes during the execution of such a task, and therefore, should be controlled by the learner. However, unlike the continuous task performed in the Munro et al. (1985) study, practice of the target location task consists of a set of individual trials. Feedback is probably not intrusive to learning in this context, so this research is considered inappropriate for examining feedback control mechanisms.

The fact that LC subjects in Experiment 1 performed at a faster rate on the immediate test than LCA and LC subjects probably indicates a lack of efficiency in the control mechanism rather than superiority of learner control. CC subjects were advanced, and LCA subjects were advised to advance to higher levels of difficulty. This seemed to temporarily change subjects' perception of "good"

performance. Shaping subjects' perceptions is probably an effective way to induce greater attention and promote greater effort on specific aspects of criterion skills. For example, it is likely that learners can be encouraged to improve their speed by increasing tolerance for error and/or decreasing task time limits. In settings where students are learning how to operate real world devices (e. g., aircraft), it is sometimes preferable to alter levels of difficulty without changing characteristics of the task.

The results of the pre-experiment have helped shape the design of Experiment 2. It is apparent that subjects did not realize the value of utilizing instructional information to closely scrutinize the task before attempting to practice it. Even when subjects realized they were missing crucial information, they were reluctant to go back and study the instruction. Control mechanisms should be more expedient than learners for analyzing on-task performance and making decisions for advancing in the instruction or engaging in remedial activities. Computer control mechanisms are being designed for Experiment 2 using cause and effect factors identified from the analyses of Experiment 1 and the pre-experiment. Although it has been demonstrated that

learners tend to follow computer-generated advice, CC mechanisms should be more efficient than LCA mechanisms. This is because computers can carrying out control decisions in a fraction of the time it takes learners to read advice, process the information, and take action.

Exercises in the instructional sequences were designed to help learners maximize their speed and accuracy on subtasks prior to attempting the criterion task. Estimating range and azimuth require fairly simple perceptual and motor skills. Observations indicate that these subskills require very little processing time after a few practice trials. However, estimating heading is more complex and involves the synthesis of symbolic and spatial information. Inducing (by advice) or forcing (by computer control) learners to master range and azimuth estimation prior to attempting heading estimation should help learners master the whole task more quickly.

Advancing from practice to the test is one of the control decisions. It is hypothesized that learners executing an unfamiliar task will not be able to maximize lesson efficiency, i. e., rate of achievement per unit of lesson time.

It is expected that control mechanisms for advisement and automatic advancement will result in greater lesson efficiency in Experiment 2. If these results are verified, generalizations can be made for designing control mechanisms for similar instructional contexts.

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